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Effects of Timber Management Practices on Insects and Diseases

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Introduction

Forests are dynamic and ever changing. They have been present on the Earth for eons--growing, developing, maturing, being destroyed, then replenishing themselves to start the process anew. Natural catastrophic events played an important role in this process. Fires, insects, and diseases eliminated and recycled the old and prepared the way for the new. In recent decades, human needs for goods and services from the forest led the way for major efforts in forest protection--we no longer consider it acceptable to have thousands of acres destroyed by fire, entire landscapes defoliated or killed by insect pests, or tree species like the American chestnut virtually eliminated by disease organisms. Our good intentions have resulted in hundreds of thousands of acres of physiologically mature forests that are "ready" for change. Pest outbreaks that are now occurring in these pathologically mature areas are effective indicators of forest condition. In other cases, modern management practices have contributed to increased forest susceptibility in quite different ways. Again through good intentions of providing goods and services from, and extending the productivity of, forest land, thousands of hectares (acres) have been planted on sites that are marginally suitable. In many cases, these efforts have resulted in huge blocks of densely-stocked, single-species, even-aged stands of high value, which are at high risk for pest attack and significant economic loss.

Properly timed stand treatments provide a balance for setting back the pace of natural succession and for reducing risk and damage from pests in intensively managed forests. This section addresses the major insects and diseases threatening the forests of the five ecographic regions of the United States, and the positive and negative influences that silvicultural treatments may have on the occurrence and severity of outbreaks of these pests.

Pest management considerations should become an integral part of integrated resource management planning. This planning should begin by carefully considering four basic questions:

1) What pests threaten at the various developmental stages of a given stand?
2) What short- and long-term impacts will the pest(s) have on the stand?
3) How does the stand (in terms of composition, structure, and vigor) influence the present and future dynamics of the pest organism(s)? and
4) Are there positive or negative effects of one pest (or treatment of that pest) on other pests?

These considerations are discussed in the sections that follow for each of the five ecological regions addressed in this report--first describing the major pests (or pest complexes), then describing relationships between common silvicultural practices and the severity of losses resulting from damage caused by these pests.

Southern Pines

Southern pine forests have long been ravaged by an array of insect and disease organisms that seriously affect their productive capacity. Each year, these organisms kill an estimated 28.3 million m^3 (1 billion ft^3) of timber, much of which is never utilized, and cause additional unmeasured losses resulting from growth reduction and quality degrade. The major pests affecting southern pines are listed in table 1, and are briefly described in the following sections.

Table 1--*Common and scientific names of major insect and disease pests affecting southern pine forests*

Reproduction weevils:	
Pales weevil	*Hylobius pales*
Pitch eating weevil	*Pachylobius picivorus*
Brown spot needle blight	*Scirrhia acicola*
Nantucket pine tip moth	*Rhyacionia frustrana*
Fusiform rust	*Cronartium quercum* f. sp. *fusiforme*
Pine bark beetles:	
Southern pine beetle	*Dendroctonus frontalis*
Black turpentine beetle	*D. terebrans*
Ips engraver beetles	*Ips avulsus*
	I. grandicollis
	I. calligraphus
Annosus root rot	*Heterobasidion annosum*
Littleleaf disease	*Phytophthora cinnamomi*

Major Pests

Reproduction Weevils--Adult reproduction weevils are attracted to fresh pine stumps, feed on young seedlings in the vicinity, and deposit their eggs in the large roots of stumps. Offspring that emerge from the roots also feed on the bark of young seedlings and often kill 20 to 30 percent of pine seedlings planted in cut-over, storm-damaged, burned, or otherwise disturbed areas. Mortality may range as high as 60 percent in localized areas. All southern pine species are susceptible to damage. Damage is most severe during February through June and less so in late summer and early fall.

Brown Spot Needle Blight--This blight occurs in all the coastal States from Virginia to Texas, and inland to Arkansas and Tennessee. All southern pines are attacked by the fungus, but only longleaf pine (*Pinus palustris*) seedlings are seriously damaged. Seedlings that are heavily infected can remain in the grass stage for several years and eventually die.

Pine Tip Moths--These moths deposit their eggs in the buds of young loblolly (*Pinus taeda*) and shortleaf (*P. echinata*) pines. Larvae developing in the buds cause tip and terminal mortality. Heavy attacks by multiple generations each year can stunt trees for up to 5-6 years. Severe recurring infestations can

cause significant reduction in height growth and long-term volume losses.

Southern Pine Bark Beetles--These are the most destructive insects affecting southern pines. There are three major pine bark beetles, or beetle groups. These are the southern pine beetle, the black turpentine beetle, and three species of *Ips* engraver beetles. All five species occur throughout the southern pine range. More than one of these species frequently occur in the same host tree and attack by one may predispose the tree to attack by another. Greatest losses occur in loblolly and shortleaf pine stands, although most of the native Southern pines are attacked.

Fusiform Rust--This rust is most common in loblolly and slash (*Pinus elliottii*) pines, but the other pine species may also become infected. Stem and branch galls caused by the fusiform rust fungus appear on all growth stages of infected pines, from seedlings to mature trees. Oaks (*Quercus* spp.), which serve as alternate hosts, are required for spread of the disease. Economic loss results from the death of trees (primarily younger seedlings), breakage of the stem at the gall, or reduction of sawtimber quality in trees not killed outright.

Annosus Root Rot--This rot is primarily a problem in thinned pine stands on well-drained soils with deep A-horizons with high sand content. Infected trees begin to die within 2-3 years after thinning. Additional mortality may occur for several years. Trees that survive in spite of infection may have reduced growth and are more susceptible to windthrow and bark beetle attack.

Littleleaf Disease--This disease most commonly affects shortleaf and, to a lesser extent, loblolly pines growing on low-quality sites. The disease rarely affects trees younger than 20 years of age and becomes increasingly severe in older, shortleaf pine stands in the Piedmont region. Future risk of infection can be determined by evaluating the site for signs of severe erosion, poor drainage, a shallow permeable layer, and early symptoms of littleleaf infection.

Silvicultural Practices

Much of the damage caused by these insect and disease pests can be prevented or reduced by properly scheduled silvicultural treatments. At the same time, however, consideration should be given to potential aggravation effects that treatment of one pest may have on others. Some of these relationships are described below.

Clearcutting--Regeneration of pine stands in clearcut areas is obtained through natural or direct seeding, or more commonly through planting. The major pests of direct concern during early stages of seedling establishment and development are pine tip moths, reproduction weevils, and fusiform rust.

The large number of stumps created during clearcutting operations provide increased attraction to adult reproduction weevils. Damage can generally be reduced to acceptable levels by delaying planting for one season after cutting to allow stumps to deteriorate and populations to subside. If planting delays are not possible, in-field sprays either before or after planting may be required.

Sites that have a history of high fusiform rust infection or sites on which future levels of infection might be expected to be high should be planted with rust-resistant seedlings or with seed from resistant geographic seed sources. Cultural practices that encourage branching, rapid growth, or otherwise result in an abundance of succulent young tissue should be discouraged. Site preparation should be minimized, fertilization delayed until age 8-10 years, and prescribed burning delayed until age 8 years or later. Risk of infection can be reduced by removing alternate-host oaks in or near the regeneration area. Losses can be offset in areas where projected future losses are high by increasing planting densities to allow for early mortality. Managers should at the same time, however, be aware of the possible conflicts between this practice and other recommendations that call for reducing stocking density to decrease future susceptibility and damage to both annosus root rot and southern pine beetle attack. The appropriate course of action will depend on management objectives, rotation length, geographic area, and site hazard.

Heavy attacks by multiple generations of pine tip moths in replanted clearcut sites can reduce growth rates of loblolly and shortleaf pines for the first 5-8 years of stand development. However, studies have shown that only those pines growing on the poorest sites suffer significant volume loss over a rotation.

Southern pine beetles and annosus root rot are of little concern in the early life of a stand established

in clear-cut areas. But future risk may be high because of stocking densities, needs for intermediate stand treatments, and projected stand values. Southern pine beetle risk can be reduced by improving drainage of low-lying sites in the Coastal Plain regions and by protecting sensitive sites during site preparation in the erosion-prone Piedmont. Where management objectives permit, mixed pine or pine-hardwood stands should be favored since they are less susceptible to beetle infestation. The threat from annosus root rot can be reduced by increasing initial spacing of seedlings planted on high-hazard sites. Wider spacing will delay the need for future thinning and will reduce root contacts through which the disease spreads. Where practical, pine species (such as longleaf) or hardwoods that are more resistant to annosus root rot may be considered.

Sites that are high hazard for littleleaf disease (or that have a previous history of the disease) should be regenerated with seed or seedlings from a seed source of shortleaf or loblolly pine that exhibits disease resistance, or with nonhost species such as longleaf pines or hardwoods. Areas that have been clearcut may also be considered for subsoiling or other drainage improvement operations where high-clay content, heavily eroded soils present high risk to littleleaf disease development.

Shelterwood--The shelterwood system provides natural regeneration and an opportunity to improve the composition and vigor of the older stand. Natural seedlings are generally less vulnerable to attack by reproduction weevils, probably because of thinner bark, reduced food base, and development under the overstory canopy. Pine tip moth damage is less severe because the treatment favors heavy ground cover and close tree spacing. Fusiform rust incidence may be high in shelterwood managed areas, but may be reduced by removing rust infected older trees to provide rust free or rust resistant overstory trees from which the new stand will develop. Damage from littleleaf disease may be reduced by making tree removal cuts early and frequently to maintain stand vigor. Early removal also recovers value from diseased trees and offers an opportunity to remove high-risk trees with increased susceptibility to other insect and disease organisms.

Shelterwood management is well suited for maintenance of high vigor stands of reduced susceptibility to bark beetles. Tree removal selections should be made to maintain stand basal area below 23.0 m^2/ha (100 $ft^2/acre$), and to remove high-risk individual trees such as those that have been struck by lightning, damaged in logging, or show rust or root rot symptoms. Where management objectives allow, species mixtures favoring hardwoods will reduce overall stand susceptibility to bark beetles. Care should be given to preventing buildup of logging residue and to not allow residue to remain in piles near residual crop trees, and to avoid making basal scars during logging, which increase risk to black turpentine attack.

Stumps created during the shelterwood operation should be treated with borax if the stand is not currently infected by the annosus root rot fungus, or treated with *Phelibia gigantea* if the disease is present. Shortleaf pine stands on high-hazard littleleaf sites should be maintained on short rotation cycles and should receive early and frequent intermediate thinnings.

Seed Tree--Fusiform rust and pine tip moths may affect regeneration in areas managed under the seed tree system; however, high stocking densities resulting from seed tree regeneration will generally tolerate the higher mortality levels. Fusiform rust infection may be reduced by removing severely infected pines and oak alternate hosts and thereby reducing the potential for infection of younger trees in the same or adjacent stands. Annosus root rot is generally not a problem in naturally regenerated stands.

Pine bark beetles may be a problem in residual seed trees, and later as dense regeneration develops into an older stand. Logging damage to seed trees may result in increased attack by black turpentine beetles. Logging residue offers opportunity for buildup of *Ips* engraver beetles. To prevent a buildup, the residue should be removed or distributed to allow for rapid drying. Developing stands may become susceptible to bark beetle attack as competition increases and vigor declines.

Group Selection--Damage by insects affecting young stands, such as reproduction weevils, will be less severe than under systems requiring extensive site preparation. Reproduction weevil and pine tip moth damage may also be less severe because there are not large quantities of host material available in which large populations can build. Fusiform rust incidence may be high because of microclimatic influences within small openings created by tree removal and

by accelerated terminal and lateral growth of trees in young stands following release.

Reduction of stand density will reduce susceptibility to pine bark beetles, but tree and site damage may increase risk under certain conditions. The extent to which treatment reduces risk or creates additional hazards depends upon care exercised during the operation, the size of tree groups removed, the size and density of untreated areas, and the pine/hardwood composition of the remaining stand. Site hazard to annosus root rot should be evaluated and stumps should be treated with borax when warranted.

Group selection may provide some beneficial effect in stands infected by littleleaf disease by increasing vigor of remaining trees. Individual tree mortality can be reduced by removal of infected and declining trees during cutting operations. In stands with less than 10-percent infection, diseased trees should be removed every 10 years; between 10- and 25-percent infection, every 6 years; and with greater than 25-percent infection, all shortleaf pines should be removed as they become merchantable and before disease symptoms become too severe.

Single Tree Selection--Openings created by removal of individual trees through single tree selection may produce microclimatic conditions that favor rust infection on young seedlings, particularly in stands where there is an abundance of oak alternate hosts. Other young-stand pests such as reproduction weevils, brownspot needle blight, and pine tip moths are rarely problems in areas naturally regenerated by selection methods because of regeneration density and presence of an overstory canopy.

As stands develop, they may be affected by fusiform rust, bark beetles, root rots, and interactions among these pests. Trees that are galled by fusiform rust are subject to breakage by wind and ice and may be infection courts for other insect and disease organisms. Single tree selection offers an opportunity to sanitize stands through infected tree removal. Removals should be made prior to prescribed burning, if it is planned, because trees with fusiform rust galls are more susceptible to fire-caused mortality, and charred cankers contaminate pulp. Annosus root rot problems may be intensified by selection removals on high-risk sites when stump surfaces are exposed to windblown spores. Damage caused by pine bark beetles is most severe in densly stocked stands with slow radial growth. Removal of selected trees that maintain basal areas below 23 m^2/ha (100 ft^2/acre) can be beneficial in maintaining vigorous tree growth. High-risk trees that may be slower growing or damaged by lightning, wind, ice, or other wounding agents should be given higher priority for selection. Caution should be exercised during summer cutting operations to avoid buildups by *Ips* engraver beetle and to prevent piling of logging residue, especially near residual crop trees. When management objectives allow, bark beetle risk can also be reduced by favoring species mixtures containing hardwoods. Damage by little leaf disease may be reduced on high-hazard sites by selectively removing obviously diseased trees. This is especially true where fewer than 25 percent of the stems are infected and/or where the residual stand will be inadequately stocked.

Pacific Coast Conifers

The Pacific coast region contains one of the largest areas of managed forests in the world. Good growing conditions, large volumes per unit area, large ownerships, (individual, corporate, and government), and extensive forests of desirable tree species contribute to the acreage under management. Silvicultural treatments are commonplace.

Insects and diseases cause significant losses in Pacific coast coniferous forests, but unlike in many other regions of the United States, the number of different pests is small. In the last 10-20 years, Pacific coast conifer stands have not experienced major defoliator or bark beetle outbreaks (with the exception of Douglas-fir bark beetle), and many diseases common in the inland western regions are not important in Pacific coast stands. Major insects and diseases of this region are listed in table 2 and are described briefly in the following sections.

Diseases of this region are listed in table 2 and are described briefly in the following sections.

Table 2--*Common and scientific names of major insect and disease pests of Pacific coast conifers*

Stem decays	Various fungi
Root diseases	
Laminated root rot	*Phellinus weirii*
Armillaria root rot	*Armillaria spp.*
Dwarf mistletoes	
Hemlock dwarf mistletoe	*Arceuthobium tsugense*
Douglas-fir dwarf mistletoe	*A. douglasii*
White pine blister rust	*Cronartium ribicola*
Douglas-fir bark beetle	*Dendroctonus pseudotsugae*

Major Pests

Stem Decays--Many different fungi are responsible for stem decays, and collectively they cause more volume loss than any other pest group affecting Pacific coast conifers. Losses caused by stem decays are steadily declining as mature and overmature forests are regenerated.

Root Diseases--The two most important root diseases of Pacific coast conifers are laminated root rot, caused by *Phellinus weirii*, and armillaria root disease, caused by *Armillaria obscura*. Many tree species are affected, but damage is most widespread in Douglas-fir stands. Damage caused by root diseases is increasing.

Dwarf Mistletoes--The most common species of dwarf mistletoes affecting Pacific coast conifers are hemlock dwarf mistletoe and Douglas-fir dwarf mistletoe. Some species of pines and true firs in northern California and southwestern Oregon are infected by dwarf mistletoes. Losses caused by dwarf mistletoes are declining sharply.

White Pine Blister Rust--White pine blister rust is still the most serious threat to western white pine and sugar pine. Losses to this disease are declining because the most susceptible trees have been killed and the survivors have more resistance.

Douglas-fir Bark Beetle--Douglas-fir bark beetle is the most significant insect affecting Pacific coast conifers. It is found only on Douglas-fir. Losses caused by this insect are diminishing, but occasional outbreaks still occur following large storms and fires.

Other--In addition to the above and other insect and disease pests, abiotic factors are playing a continuing and increasing role in the health of Pacific coast conifers. Storms, especially those accompanied by large amounts of precipitation and strong winds, are responsible for enormous volumes of windthrown timber. Air pollution is a factor, but has not as yet caused extensive injury to Pacific coast conifers because of proximity to strong onshore winds of the Pacific Ocean.

Silvicultural Practices

With few exceptions, the major forest insect and disease problems of Pacific coast conifer stands are dealt with by silvicultural treatments rather than with pesticides. Losses from the major insects and diseases affecting Pacific coast conifers are greater in unmanaged stands than those where any of the five silvicultural systems are being diligently applied. The effectiveness in altering stand risk to insects and diseases varies with the specific pests and

silvicultural system being used. These relationships are summarized in the section that follows.

Clearcutting--Clearcutting has the best potential for reducing pest-caused losses. Because all trees are removed, there is less opportunity to leave pest-affected trees than with other systems. Clearcutting provides the best opportunity for managing root disease of Pacific coast conifers because tree species that are less susceptible can be planted in the cleared areas; also, infection centers can be accurately located and defined, and infected stumps that introduce infection into future stands can be removed following clearcutting. And, if done correctly so no dwarf mistletoe-infected residuals or infected trees are left on the edges of the openings, clearcutting can result in local eradication of this group of pests.

Shelterwood and Seed Tree--These two silvicultural systems have lower potential for perpetuating insect and disease problems than the selection systems. The greatest risks associated with shelterwood and seed tree cuts are from stem decays and dwarf mistletoes. Overstory trees should be removed soon after regeneration is successfully established to prevent excessive physical damage to the small trees from logging. Dwarf mistletoe-infected trees should not be left to provide seeds or shade for the regenerating stand and should be removed before the regeneration reaches 0.9 m (3 ft) tall to minimize infection of the susceptible seedlings. Douglas-fir bark beetles can build up in windthrown trees, and thus care should be taken with shelterwood, seed tree, and clearcuts to place boundaries of cutting units in locations where windthrow of edge trees will be minimized.

Single Tree Selection--Single tree selection has the greatest potential of all silvicultural systems to increase or maintain high risk to the major insects and diseases affecting Pacific coast conifer stands. Practically all stem decay is initiated with wounds on trees. Single tree selection results in a high degree of tree wounding because of the number of stand entries and limited maneuvering room for equipment associated with this approach. Most of the tree species that regenerate naturally in single tree selection systems, such as hemlocks and true firs, are also those that are most damaged by stem decays. Trees with stem decays or large wounds could be removed during subsequent single tree selection entries.

Root diseases may also be perpetuated through single tree-selection because infected, but nonsymptomatic, trees are more likely to be left than with other silvicultural approaches. Wounding during stand entries also makes trees and stands more subject to damage from Armillaria root disease and annosus root and butt rot.

Selection systems that create multiple canopy levels have the greatest potential for perpetuating dwarf mistletoe infestations. It is difficult to successfully practice single tree and group tree selection in stands with widespread dwarf mistletoe, particularly if openings created by tree harvesting are large enough to encourage regeneration of susceptible species.

Group Selection--Group selection has less potential of increasing susceptibility to insects and diseases than single tree selection, but removal of many small groups of trees can result in many of the same root disease, stem decay, and dwarf mistletoe problems. The potential for damage should decrease as the size of the tree groups removed increases. On the other hand, removing groups of trees affected by stem decays, dwarf mistletoes, and root diseases can also improve overall stand condition. Dwarf mistletoes can also be a continuing problem in group tree selection areas because infected trees are often left, and the system generally results in a multicanopy structure that exacerbates mistletoe spread.

Single tree and group selection systems have good potential for preventing outbreaks of Douglas-fir bark beetles. Under these systems, infested trees can be quickly salvaged before the beetles have the opportunity to spread to adjacent trees. This can be done without harvesting the entire stand.

Other Stand Management Practices--Precommercial thinning is a common practice in Pacific coast conifer stands. Susceptibility to Armillaria root disease can be lowered by thinning to avoid stress from overstocking. Care should be taken during precommercial thinning activities to avoid wounding crop trees. Similarly, thinning provides an opportunity to favor tree species that are less susceptible to organisms that cause stem decays. Dwarf mistletoes can be reduced by combining stand cleaning with thinning.

Planting provides an opportunity to reforest sites with tree species that are not susceptible to root pathogens and dwarf mistletoes that may be on a site. Similarly, planting of rust-resistant western white

pine (*Pinus monticola*) and sugar pine (*P. lambertiana*) seedlings is the most effective method of preventing losses to white pine blister rust on sites where damage from this disease has been common in the past.

Pruning is not commonly practiced in Pacific coast conifer stands; however, if it is done properly, it can effectively reduce damage caused by stem decays, dwarf mistletoes, and white pine blister rust. In the case of white pine blister rust, cankered branches and lower crown branches (where lethal tree infections are most likely to occur) are removed. Pruning is usually done in combination with thinning.

Western Inland Conifers

Ponderosa pine (*Pinus ponderosa*), lodgepole pine (*P. contorta*), western white pine, larch (*Larix* spp.), Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), white fir (*A. concolor*), red fir (*A. magnifica*), and Englemann spruce (*Picea engelmannii*) are the most important western inland conifers. These tree species are plagued by a large number of insect and disease pests, and large outbreaks are relatively common. The most important groups of insects and diseases are presented in table 3.

Table 3--*Common and scientific names of the most important insects and diseases affecting western inland conifers*

Stem decays	Various fungi
Root diseases:	
Laminated root rot	*Phellinus weirii*
Armillaria root rot	*Armillaria* spp.
Annosus root rot	*Heterobasidion annosum*
Dwarf mistletoes:	
Western dwarf mistletoe	*Arceuthobium campylopodum*
Lodgepole pine dwarf mistletoe	*A. americianum*
White pine blister rust	*Cronartium ribicola*
Hard pine rusts:	
Western gall rust	*Endocronartium harknessii*
Comandra blister rust	*Cronartium comandrae*
Western spruce budworm	*Choristoneura occidentalis*
Douglas-fir tussock moth	*Orgyia pseudotsugata*
Bark beetles:	
Mountain pine beetle	*Dendroctonus ponderosae*
Western pine beetle	*D. brevicomis*
Douglas-fir bark beetle	*D. pseudotsugae*
Spruce beetle	*D. rufipennis*

Major Pests

Stem Decays--True firs (*Abies* spp.) and spruces (*Picea* spp.), in particular, suffer large volume losses from stem decays. Pines, Douglas-fir, and larch are affected, but to a lesser extent. Many different fungi are responsible. Losses from stem decays are steadily declining as more western inland conifer stands come under management, and as overmature stands are regenerated.

Root Diseases--Laminated root rot, armillaria root disease, and annosus root and butt disease are the most important root diseases of western inland conifers. Root disease incidence and damage appear to be steadily increasing.

Dwarf Mistletoes--Vast areas of western inland conifer stands are infested by dwarf mistletoes. Most tree species are affected, but ponderosa pine, lodgepole pine, Douglas-fir, and larch are most seriously impacted. The area infested by dwarf mistletoes is slowly declining.

White Pine Blister Rust--This disease is the greatest threat to western white pine and other five-needle pines. It occurs over almost the entire range of western white pine. Losses from blister rust are declining.

Hard Pine Rusts--Western gall rust and commandra blister rust are the most damaging rusts of two- and three-needle pines. These rust fungi cause galls and cankers, resulting in growth loss, deformities, top-kill, and tree mortality. Losses from these diseases may be declining slowly.

Western Spruce Budworm--This is the most damaging and widespread of the several insects that defoliate western inland conifers. True firs and Douglas-fir are the preferred hosts for western spruce budworm. Losses from western spruce budworm are steadily and sometimes dramatically rising in response to the increasing acreage of susceptible fir forests.

Douglas-fir Tussock Moth--Outbreaks of this insect occur less frequently and persist shorter than western spruce budworm, but damage in defoliated stands can be more severe. Western inland firs are the preferred hosts. Outbreaks appear to be on the decline.

Bark Beetles--The major bark beetles of western inland conifers include mountain pine beetle, western pine beetle, Douglas-fir bark beetle, spruce beetle, and fir engraver. Together, these and less important bark beetles kill tremendous volumes of trees. Most bark beetle outbreaks develop in stands that have been damaged by storms or fires, or are under stress from factors such as defoliators, overstocking, drought, and root diseases. Losses from bark beetles are slowly declining, as hundreds of thousands of acres of preferred-host types have been destroyed, but very large outbreaks still occur.

Silvicultural Practices

Vast areas of western inland conifers have received treatments for pests, particularly dwarf mistletoes, white pine blister rust, western spruce budworm, tussock moth, and bark beetles. Defoliators, such as western spruce budworm, have been sprayed with several insecticides. Most of the other pests have been treated using cultural methods, with large areas having had some harvesting or other silvicultural treatment. These activities have had a significant effect on pest damage.

In general, stands that are not managed experience more frequent and damaging pest attacks than those treated under any of the five major silvicultural systems.

Single Tree Selection--This silvicultural system poses the greatest risk of continued depredations of western inland conifer stands from the major pests. The potential for losses from stem decays is high because operations conducted during single tree selection typically result in more wounds that serve as infection courts for decay causing fungi. Single tree selection also favors shade-tolerant species that generally suffer the greatest losses from decays. Losses from stem decays can be reduced by taking actions to minimize tree wounding and to remove decayed and scarred trees. Root diseases are most serious in stands managed under single tree selection, primarily because this approach has the greatest potential of leaving infected, but nonsymptomatic, root-diseased trees. Tolerant and semitolerant tree species that are favored in the single tree selection process are also those most susceptible to root diseases. Multiple entries provide a continuing supply of fresh stumps for some for root disease fungi to colonize and spread outward to infect adjacent trees. Dwarf mistletoes are also most likely to be perpetuated by single tree selection because lightly infected trees are likely to be overlooked and left. The mistletoes may flourish

because small openings caused by single tree removals provide sufficient sunlight for mistletoes to produce vigorous aerial shoots and seeds. Single tree selection is also likely to result in multiple-canopy structures that facilitate mistletoe spread and intensify damage. Western spruce budworm and Douglas-fir tussock moth are more likely to be problem pests in the multicanopy stands, with understories of firs resulting in stands managed by single tree selection.

Single tree selection can lower the risk of damage from white pine blister rust, hard pine rusts, and bark beetles and provides opportunities to quickly remove individual pest affected or highly susceptible trees that could serve as foci for outbreaks that could threaten adjacent trees and stands.

Group Selection--This silvicultural system poses many of the same risks for perpetuating major pest problems as did single tree selection. However, the risk is lowered as the size of groups of trees removed increases. Opportunities for treatment of several of the pests improve with the size of openings created. For example, removal of large groups of trees presents lower risk of wounding trees, and thus contributes to less stem decay than with removal of small groups. Similarly, group selection presents opportunities to remove all trees with root diseases and dwarf mistletoes from infection centers and all bark beetle trees from infested spots, especially if the groups can be made large. Group selection presents a better opportunity to plant less susceptible or immune species than single tree selection.

Care needs to be taken in prescribing group selection in stands infested with dwarf mistleoe. If the openings created are small and reforest with susceptible species, the trees in the openings will quickly become infected and will suffer heavy losses. Openings should be large enough to remove all infected trees, otherwise, they should be reforested with immune species.

Group selection also has high potential for increasing the risk from western spruce budworm and Douglas-fir tussock moth by creating multiple-canopy stands and encouraging regeneration of tolerant and semitolerant tree species preferred by these insects. On the other hand, the risk from these insects can be reduced if the openings are large enough to reforest with nonsusceptible species.

Shelterwood and Seed Tree--These two silvicultural systems pose significantly lower risks of perpetuating pest damage than selection systems. Removal of a greater portion of the trees means there is reduced likelihood of leaving pest-infested or highly susceptible trees. Detection and treatment of root diseases are improved because some of the root diseases will produce symptoms of stain and decay that can be seen on freshly cut stump surface even though these trees may not show crown symptoms. This allows more precise delineation of infection centers than is possible with selection systems. Shelterwood and seed tree systems also provide more opportunities to reforest sites with tree species immune, or with low susceptibility, to pests.

The greatest risks associated with shelterwood and seed tree systems are from mechanical injury to understories that may occur during final overstory removal and from dwarf mistletoes spreading from overstory trees. Overstories should be removed as soon as seedlings become established to prevent excessive logging damage to developing reproduction. Shelterwood and seed trees should be carefully selected to be free from dwarf mistletoe infections and should be windfirm to avoid bark beetle buildups in trees that might easily be windthrown. If trees infested with dwarf mistletoe are left to remain, they should be removed before understory trees reach 0.9 m (3 ft) tall.

Clearcutting--Clearcutting presents the lowest risk of perpetuating insect and disease problems. Complete tree removal provides an opportunity to remove all pest-affected and highly susceptible trees. It also offers the best prospects for detecting and successfully treating root diseases, either by reforesting with less susceptible tree species or by stump removal. Similarly, it presents the best chances for controlling dwarf mistletoes, because all infected trees can be included within the cut boundaries and the site can be reforested with alternative species. The risk from western spruce budworm and tussock moth can be minimized by clearcutting because less susceptible tree species can be replanted, and the resulting single-story stands typically suffer less damage than multiple-canopy stands that often develop by other silvicultural approaches.

Other Stand Management Practices--Extensive areas of western inland conifers are precommercially thinned. Such thinning can be effective in reducing susceptibility to all the major pests. Thinning provides

an opportunity to remove scarred trees and species with high stem-decay potential and to discriminate against trees with dwarf mistletoes, rust infections, and insect-caused damage. Unless precommercial thinning is done very carelessly, it will result in reduced pest susceptibility.

Prescribed burning has become a common management tool in western inland conifer forests. If done carelessly, so trees are burned, stem decays and bark beetles will increase. Most burning is carefully executed and can result in reduced pest susceptibility, particularly to root diseases, western spruce budworm, and Douglas-fir tussock moth. Prescribed burning can be effective in preventing encroachment of tolerant and semitolerant tree species into pine sites. These tolerant tree species are subject to more damage from stem decays, root diseases, and defoliators than seral tree species.

Pruning is not a common silvicultural practice, however, it does have good potential for reducing susceptibility to some pests, particularly white pine blister rust, hard pine rusts, dwarf mistletoes, and stem decays. It may be particularly useful in high-use or high-value areas.

Northeastern Conifers

The northeastern conifer forests are not really a specific entity but a wide-ranging mixture of forest types. These types vary from the extensive spruce-fir forests of northern New England and the Lake States to scattered pine stands interspersed with hardwood stands, to mixed conifer-hardwood stands. Ranging from Maine to Minnesota, to Tennessee to Georgia, it includes the following types and species: Red pine (*Pinus resinosa*), jack pine (*P. banksiana*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), northern white-cedar (*Thuja occidentalis*), spruce-fir (balsam fir (*Abies balsamea*)), red spruce (*P. rubens*), and white spruce (*P. glauca*)), eastern white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), and pitch pine (*Pinus rigida*). By far, the largest acreages occur in the boreal forest areas of Minnesota, Wisconsin, and Michigan; and in Vermont, New Hampshire, Maine, and northern New York,. A number of insect and disease organisms infest these stands, but most of them have relatively minor local impacts and are specific in the species they attack. The major pest organisms resulting in significant impacts are listed in table 4. Brief descriptions of these pests and their damage follow.

Table 4--*Common and scientific names of major insect and disease pests affecting northeastern conifer forests*

Stem decays	Various fungi
Root diseases:	
Shoestring root rot	*Armillaria* spp.
Annosus root rot	*Heterobasidion annosum*
Scleroderris canker	*Gremmeniella abietina*
Eastern dwarf mistletoe	*Arceuthobium pusillum*
White pine blister rust	*Cronartium ribicola*
Insects:	
White pine weevil	*Pissodes strobi*
Eastern spruce budworm	*Choristoneura fumiferana*
Jack pine budworm	*C. pinus pinus*

Major Pests

Stem Decays--Many different fungi contribute to stem decays of northeastern conifers, especially in the spruce-fir type and to a lesser degree, in the other species. Volume losses are quite large, especially in older mature and overmature stands.

Root Diseases--The two most important root diseases of Northeastern conifers are shoestring root rot and annosus root rot. Most species in the northeast are affected. Shoestring root rot is a problem when conifers are planted on hardwood sites following cle   itting. Annosus root rot is a problem in thinned pir   ands, especially on well-drained, sandy soils.

Scle derris Canker--A serious disease of conifers; hard pines (red, jack, and Scots) are most susceptible, while white pine and spruces are resistant, but may be attacked, and balsam fir is immune. The fungus attacks the bud and progresses down the shoot, killing the needles. Branches and main stems up to 7.6 cm (3 in) in diameter develop cankers and may be girdled. The tree is usually killed by the loss of foliage. Asexual spores are spread by rain, and sexual spores by wind. The American strain is primarily a problem on planted and natural seedlings. An aggressive "European" strain in New York and Vermont is especially damaging to large trees in red pine plantations and is increasing its territory.

Eastern Dwarf mistletoe--Dwarf mistletoe is a native parasitic plant found primarily on black spruce and occasionally on red spruce, white spruce, and tamarack. The organism causes branch swelling and masses of twigs, called witchesbrooms, on the host. The mistletoe receives its energy from the tree and several infections on the tree can reduce its vigor enough to kill it.

White Pine Blister Rust--White pine is the single most important coniferous species of the northeast. It grows in pure, natural stands, in mixed conifer stands, in mixed hardwood-conifer stands, and in plantations. White pine blister rust is a disease that begins in the needles, spreads into the branches and stems, and eventually kills the tree via trunk infections. The disease has eliminated white pine from some portions of its range and restricts planting on certain sites within the range.

White Pine Weevil--The white pine weevil prefers eastern white pine and jack pine but can also attack Norway spruce, Scots pine, pitch pine, and red pine. Adults and larvae feed on the previous year's leader and kill all of the branches above the feeding site. One or more lateral shoots may replace the leader, resulting in a crooked or forked stem and small, bushy trees, severely reducing the volume and quality of the stem. Open-grown plantations of white and jack pine are highly susceptible, especially in the northeastern and central portions of white pine's range.

Eastern Spruce Budworm--The spruce budworm prefers to feed on balsam fir, but white, red, and black spruce are suitable hosts and occasional heavy feeding occurs on hemlock; lesser feeding occurs on pines and larches. Defoliation of needles and mining of buds by the budworm has impacted millions of hectares (acres) of spruce-fir forest in the Northeast, resulting in mortality and growth loss on a large scale. Natural outbreaks occur in mature and overmature stands, especially those stands containing large numbers of balsam fir.

Jack Pine Budworm--The jack pine budworm is closely related to the spruce budworm. It prefers to feed on jack pine and will also feed on small red, Scots, and white pine trees in the understory. Defoliation of needles and mining of buds by the budworm results in topkilled and stagheaded jack pine trees, but only rarely do larger trees die. Mortality can be quite heavy in younger understory pine trees (poles, saplings, and seedlings) that are defoliated beneath a jack pine overstory. The jack pine budworm is currently the most serious conifer insect pest in the Lake States.

Silvicultural Practices

These eight major pests interact with the management of northeastern conifers in many ways. In the following discussions of silvicultural systems, only positive and negative interactions of pests, their host forest type, and silvicultural treatments are mentioned. Neutral or unknown effects are not discussed.

Single Tree Selection--Single tree selection is generally used in only two of the northeastern conifers--the spruce-fir type and eastern hemlock. Since single tree selection car·es large trees at all times, it has the potential to increase the significance of stem decays in those stands for all types of northeastern conifers if logging damage is not minimized. The periodic cuttings required will also

increase the potential for damage due to root diseases, especially annosus root rot. The regeneration of new seedlings under the older trees provides an ideal situation for the spread of eastern dwarf mistletoe, unless all infested trees are removed and destroyed in the selection cutting. In the spruce-fir type, single tree selection cutting increases spruce at the expense of balsam fir, reducing the susceptibility of the stand to spruce budworm. However, the continual presence of large susceptible trees under single tree selection will offset some of the reduction in susceptibility due to changing the species composition.

Group Selection--This system has the same advantages and disadvantages as single tree selection, but it may offer a few additional advantages. It can be used with white and red pine, while single tree selection cannot. If eastern dwarf mistletoe infections are patchy, a group selection cut could effectively remove all of the infested trees. Group selection could also isolate a discrete root disease pocket and prevent it from spreading. Balsam fir may be more plentiful in group selection cuts resulting in higher susceptibility to spruce budworm, but large trees are not present in the groups reducing susceptibility.

Shelterwood--The shelterwood system has great potential for reducing the impacts of several damaging agents. The system can be used with almost all of the various northeastern conifers. Even-aged systems, including shelterwoods, can reduce losses to stem decays by shortening rotations so large mature and overmature trees are not present. Annosus root rot can be prevented in these stands by applying *Phlebia gigantea*, a competing fungus, to the stumps, or by treating freshly cut stumps with borax. Shelterwood cuts can be used to reduce Eastern dwarf mistletoe provided all infected trees are removed in the shelterwood cut. Otherwise, new seedlings may become infected.

The most important use of shelterwoods for pest reduction has been the reduction of white pine weevil damage on white pine. Regenerating white pine under 30-50 percent shade (or tree cover) will reduce white pine weevil attacks on the leaders and branches of these trees. Once the white pines are 3.7-7.6 m (12-25 ft) tall, the shelterwood can be removed. The weevil will then attack the trees, but the damage will be above the first log of the tree, greatly reducing the economic impact of the weevil. The use of shelterwoods for reduction of white pine weevil damage does not work on jack pine. Shelterwoods are also an excellent choice for reducing spruce budworm impacts. Using shelterwood cuts will increase the amount of spruces and reduce the amount of balsam fir in the stand, decreasing the stand susceptibility. The shelterwoods also favor birds that prey on spruce budworms.

Seed Tree--Seed tree cutting is not used with any regularity in northeastern conifers. While it has many of the same advantages as the other even-aged systems, seed tree cuts do not leave as much shade as shelterwoods and tend to be susceptible to windthrow of the seed trees. Their major use is in mixed conifer--hardwood stands where white pine, in particular, is retained as seed trees to increase its composition in the stand.

Clearcutting--This system is the most common regeneration system used in Northeastern conifers. Depending upon the forest type or species involved, regeneration can be obtained from natural seedlings or artificially by planting nursery stock. As mentioned under shelterwoods, shortening rotations by clearcutting mature and overmature stands will minimize stem decays and will also reduce spruce budworm susceptibility (for example rotations of 45-70 years for spruce-fir). Conifers should not be planted on hardwood stump sites unless the stumps are removed to prevent shoestring root rot from killing the seedlings. The American strain of scleroderris canker can be minimized by using disease-free planting stock and carefully selecting planting sites to avoid high-hazard sites and sites adjacent to infested stands. The European strain can be slowed by clearcutting the entire infested stand and destroying all needle-bearing slash by fire or other means. Clearcutting followed by the destruction of all infested trees is the best treatment for stands heavily infected by Eastern dwarf mistletoe. Fire can also be used to eliminate the infested slash. Clearcutting will increase the damage to white pine by white pine weevil in the northeastern and central portions of its range. Damage to jack pine weevil is also increased by clearcutting, but damage can be minimized by very close spacings when planting or very dense stands of natural regeneration. The dense stands help train the new leaders and prevent the formation of small, bushy trees that never recover. Selection of planting sites to avoid high-hazard sites and planting resistant seedlings can be used to reduce white pine blister rust damage following clearcutting. Clearcutting

spruce-fir stands will increase the amount of balsam fir in them resulting in higher susceptibility to spruce budworm. However, clearcutting can be an effective treatment to eliminate high-risk spruce-fir stands prior to an outbreak. Clearcutting heavily infested stands before maturity can reduce the impact of jack pine budworm.

Other Cultural Practices--Fire or prescribed burning has been mentioned as a valuable tool for destroying disease-infected slash in the previous text. Fire can also reduce the number of some stem decay fruiting bodies in a stand prior to cutting. However, the fire has a risk for wounding trees, providing an entry for stem decays if too hot a fire is used. Logging damage from thinnings also provides wounds for stem decays to invade trees. Pruning can be used to remove branches infested with eastern dwarf mistletoe, scleroderris canker, and white pine blister rust. This treatment prevents the tree from being killed and reduces spread of the diseases to other trees. Intermediate thinnings can be used to remove infected trees (particularly effective in young stands lightly infected with Eastern dwarf mistletoe), favor nonsusceptible species, maintain vigorous stands, shorten rotations, and presalvage trees before they die. Removal of topkilled and stagheaded jack pine trees in thinnings is the only known treatment for reducing impact of jack pine budworm. When doing thinnings in northeastern conifers, logging damage should be minimized to prevent stem decays and stumps should be treated to prevent annosus root rot, as described earlier. Avoiding high-hazard planting sites and selecting resistant genotypes and species will prevent many pest problems from developing. Eradication of *Ribes* spp., alternate hosts of white pine blister rust, can be used to protect some high-value stands in local areas. Diversifying the age classes present in an area will reduce the risk that the entire area will become susceptible to a single pest outbreak.

Eastern Hardwoods

The eastern hardwood forest is a mixture of species and forest types. The largest single type is oak-hickory, covering 46.1 million hectares (114 million acres) in an area bounded by Texas and Florida in the south and Minnesota and Maine in the north. The type is most concentrated in the Appalachian Mountains and Plateaus and the Ozark and Ouachita highlands. Species include numerous oaks and hickories and smaller amounts of many other hardwoods and conifers. An important subtype is 10.5 million hectares (26 million acres) of Appalachian mixed hardwoods that is dominated by yellow-poplar, oaks, ashes, black cherry, maples, and many other species. The next largest type, bottomland hardwoods, occurs along the 21.0 million hectares (52 million acres) of river floodplains, drainages, and swamps in the Eastern United States. Principal species include cottonwood, willows, sycamore, gums, silver maple, several oaks, and many minor species. The oak-pine types cover 14.2 million hectares (35 million acres) and consist of many of the species found in the oak-hickory type along with with pines. The pines include either northern species like pitch, or more southern ones like Virginia, shortleaf, and loblolly. This oak-hickory type occupies a transitional phase between pine and hardwood types. Northern hardwoods, dominated by sugar maple, American beech, yellow birch, and its major subtype, cherry-maple (dominated by black cherry and red maple) cover 8.9 million hectares (22 million acres) in the northern half of the Eastern United States. The remaining hardwood type, aspen-birch, covers 6.1 million hectares (15 million acres); aspens (bigtooth and quaking) dominate in the Lake States, and birches (primarily paper birch with some gray birch) dominate in New England. There are well over 200 species in the eastern hardwood forest and a large number of insects and diseases attack them; most of these pests have minor, local impacts and do not cause large outbreaks. However, certain major pest organisms cause significant impacts; these are listed in table 5.

Brief descriptions of these pests and their damage follow the table.

Table 5--*Common and scientific names of major insect and disease pests affecting eastern hardwood forests*

Gypsy moth	*Lymantria dispar*
Other defoliators	Various insects
Root diseases:	Various fungi
Shoestring root rot	*Armillaria* spp.
Stem decays	Various fungi
Stem borers	Various insects
Beech bark disease complex:	*Nectria coccinea* var. *faginata* *Cryptococcus fagisuga* *Xylococculus betulae*
Vascular and canker diseases:	
Chestnut blight	*Cryphonectria parasitica*
Dutch elm disease	*Ophiostoma* (*Ceratocystis*) *ulmi*
Oak wilt	*Ceratocystis fagacearum*
Sapstreak disease	*Ceratocystis coerulescens*
Declines (diebacks)	Various stress agents and factors and secondary-action organisms
Reproduction insects	Various insects

Major Pests

Gypsy Moth--An introduced pest, the gypsy moth is a defoliator of leaves of more than 500 species, but it especially favors oaks. When larvae are half-grown, they will eat many hardwoods and conifers. Ashes, yellow-poplar, black walnut, and some other species will not be eaten. Defoliation occurs in May and June, usually followed by a new growth of leaves in July. This refoliation process considerably weakens the tree, allowing other insects and disease agents to attack and kill it. Mortality can vary from very light to complete and is increased by drought stress. The nuisance of gypsy moth larvae also creates problems in recreation areas, rural housing areas, and small cities and towns. The gypsy moth is still increasing its range in the United States and eventually will be present over much of the eastern hardwood area.

Other Defoliators--Almost every hardwood species has at least one native defoliator. Some defoliators are specific to one or two species, while others may eat 10 to 20 species; a few eat hundreds of species. Some are spring and some late summer defoliators. Native defoliators periodically reach outbreak proportions in local areas and may cause damage on a scale similar to gypsy moth in these localized situations. Drought stress seems to play an important role in some of these outbreaks. Examples of recent local outbreaks are: cherry scallop shell moth in northwestern Pennsylvania; looper complex in Indiana, Pennsylvania, and West Virginia; forest tent caterpillar and eastern tent caterpillar in New

England; and oak leaftier and leafroller in Pennsylvania.

Root Disease--A number of root diseases cause problems with hardwoods, especially when seedlings are grown in nurseries. The major root disease problem, however, is *Armillaria* spp., the shoestring root rot. *Armillaria* plays an important ecological role in helping to kill and decay roots from trees that cannot compete against healthier, more vigorous trees. It is usually present in all stands. When trees are weakened by stress, such as defoliation, the fungus is able to successfully invade and kill them.

Stem Decays--A number of fungi contribute to stem decays of eastern hardwoods. Some fungi are species-specific, while others attack a wide range of species. Volume losses and degrade are large, especially in older mature and overmature stands.

Stem Borers--A number of insects bore through the wood of hardwood trees, damaging the wood and creating degrade losses worth millions of dollars each year. Some insects, such as carpenterworm and red oak borer, can bore right into the wood, creating holes and tunnels that reduce value. Other insects, such as the twolined chestnut borer, bore in the inner bark and sapwood, first girdling branches and eventually the main stem. They are especially active in trees that have been weakened by drought stress or defoliation, and their activity can kill these trees.

Beech Bark Disease Complex--Beech bark disease is an introduced insect-fungus complex that kills or injures American beech. Two scale insects (see table 5) pierce the bark of beech and then feed. The fungi, *Nectria* species, then infects the bark through these feeding wounds. The tree walls off the damaged area, creating defects and slow growth. Many trees are killed as the bark becomes completely girdled. In 1987, beech bark disease was the second most important disease in New York in terms of volume loss. A few trees show genetic resistance to scale infestation.

Vascular and Canker Diseases--Several vascular and canker diseases have had a major impact on specific hardwoods. Chestnut blight fungus was introduced to the United States in 1904 and has killed nearly all of the mature American chestnut (*Castanea dentata*) trees. The fungus enters through wounds and produces cankers on branches and stems, eventually girdling the tree. However, the roots are not killed, so many trees keep sprouting; most of these sprouts are invaded and eventually killed. The Dutch elm disease fungus also was introduced from Europe. This fungus infects the sapwood of the tree, usually starting in the branches and working down into the stem. Leaves wilt, then branches die, and eventually the entire tree is killed. The fungus is spread by two species of elm bark beetles. Dutch elm disease has almost eliminated mature elm trees from eastern hardwood forests. As with chestnut blight, many small elm trees can be found, but most of these are killed before they mature. Another major disease is oak wilt. This fungus is closely related to the fungus causing Dutch elm disease and works in a similar fashion by invading the the vessels in the wood. Oak wilt is also spread by bark beetles and other insects. Like Dutch elm disease, oak wilt is spread locally through root grafts with adjoining trees. The fungus has killed large numbers of oaks, but it is not as widespread as the previous two diseases. Sapstreak disease of sugar maples is not a significant problem at this time , but it has the potential to become one as management intensifies in the northern hardwood forest type. The fungus, a common sapstaining organism of lumber and wood, becomes lethal when it gains access to the living tree through basal wounds.

Declines (Diebacks)--Dieback and decline are complex diseases triggered by biotic or abiotic stress factors (for example drought, defoliation). Several of the most significant are ash, oak, and maple declines. Beech bark disease, sweetgum blight, and birch dieback are other examples. Terminal branches of trees die back. Trees often become stagheaded. Affected tree mortality is usually the result of stressed trees being attacked by secondary organisms. New research techniques have now provided evidence that one ash decline disease (ash yellows) is caused by a mycoplasma-like organism (MLO).

Reproduction Insects--A number of insects attack seeds and seedlings of hardwoods, especially oaks. *Curculio* weevils can destroy a large percentage of oak acorn crops and can be an important pest in oak, pecan, and walnut seed orchards. Several other species attack both seeds, germinating seedlings, and young seedlings. Some of the most damaging of these insects are *Conotrachelus* weevils, which eat root tissue and kill the new seedlings.

Silvicultural Practices

The above-mentioned pests have both positive and negative interactions with the management of eastern hardwoods. It is interesting to note that many of these destructive pests are introduced from Europe and Asia. Because they are not native pests, they have not been as effectively controlled by the use of management practices. In the following discussions of silvicultural systems, only positive and negative interactions of pests, their host forest type, and silvicultural treatments are mentioned. Neutral or unknown effects are not discussed.

Single Tree Selection--Single tree selection is used only in the northern hardwood type and, to a limited extent, in the cherry-maple and Appalachian mixed hardwoods subtypes. It can be used to reduce the impact of beech bark disease by removing infected trees, large overmature trees, and rough-barked trees in favor of smooth-barked beech trees and resistant beech trees. Individual trees with decline symptoms can be removed using single tree selection. Removing large, overmature trees and logging-damaged trees, and minimizing logging damage will minimize stem decays. Periodic cuttings increase the potential for shoestring root rot damage, if additional stress occurs. Wounds made to residual maple trees afford entry to the sapstreak fungus.

Group Selection--The advantages and disadvantages of single tree selection apply as well to group selection. When used in the oak-pine and oak-hickory types, this system may more quickly help shift species composition toward more tolerant species. This shift will increase diversity and reduce susceptibility of the stand to gypsy moth. Group selection has the advantage over single tree selection for removing larger patches of susceptible beech trees or for removing susceptible trees in an oak wilt pocket. Potential damage from shoestring root rot is lower in group selection than in single tree selection.

Shelterwood--The shelterwood system is the regeneration system of choice for many eastern hardwoods when advanced seedling reproduction is not present. It is used for all types except pure aspen stands. Even-aged systems, including shelterwoods, seed tree, and clearcutting, can reduce losses to stem decays by shortening rotations. Shelterwoods can be used to promote increased species diversity and resistant clones of beech to reduce beech bark disease complex impacts. Declines can be treated by using shelterwoods to regenerate unaffected trees and remove affected trees. *Armillaria* potential is increased temporarily after a shelterwood cut. If stress or defoliation occurs in this time period, significant mortality may occur. Gypsy moth and other defoliators can reduce seed production and success of shelterwood cuts. The increased diversity of species that results from shelterwood harvests will reduce the potential for defoliation impacts in the new stand.

Seed Tree--Seed tree cutting is not used in most of the eastern hardwoods and only rarely in northern hardwoods. Windthrow is a problem with seed trees and can be increased by stem decays or shoestring root rot in the large, mature seed trees.

Clearcutting--This system is the most common regeneration system in eastern hardwoods. Most regeneration is obtained from natural seedlings or sprouts. The only artificial regeneration is in bottomland hardwoods and stripmine reclamation. As mentioned previously, stem decays can be reduced by shortening rotations. Even-aged stands with high concentrations of a single preferred species or of a few preferred species have increased susceptibility to gypsy moth and other defoliators. *Armillaria* is minimized by the long periods between cuttings and by maintaining fast-growing, vigorous trees. Beech bark disease in stands can be reduced by treating diseased trees and sprouts with herbicides and then clearcutting to encouraging other species. Stands with declines can be clearcut to regenerate new stands.

Other Cultural Practices--Fire or prescribed burning has shown potential for reducing populations of reproduction insects that live in the litter. It can also reduce the number of stem decay fruiting bodies in a stand prior to cutting. However, if too hot a fire is used, it can wound trees and encourage stem decays. Pruning can increase stem decays if done on branches larger than 2 inches. It also may provide an entry for oak wilt if done during the growing season and can increase the level of that disease. Site preparation (removing infested stumps and roots) can reduce shoestring root rot and oak wilt, but is an expensive treatment. Intermediate thinnings and timber stand improvement cuts can be used to remove infected trees, favor nonsusceptible species, maintain vigorous stands, provide shorter rotations, presalvage trees before they die, and salvage dead trees. It is a positive treatment for most pests listed in table 5,

especially stem borers. Thinnings have the potential for a negative interaction with shoestring root rot. Shoestring fungus levels can increase shortly after cutting, resulting in mortality if the stand is stressed or defoliated. Logging damage to residual trees during thinnings should be minimized to prevent an increase in stem decays and in sapstreak disease. Also, timber stand improvement (TSI) operations that create stump "wounds" when members of sugar maple sprout clumps are removed can create infection entry points for sapstreak disease. Diversifying the age classes and species compositions present in an area will reduce the risk that the entire area will become susceptible to a single pest outbreak. Managing for and matching the proper species to the site will encourage vigorous, pest-free stands and minimize stress that can trigger pest problems.

Summary

The most effective approach for reducing pest-caused damage to our Nation's forests is to focus on low pest populations and to apply treatments that will reduce the frequency of outbreak occurrence and minimize severity of outbreaks. Preventive silvicultural treatment offers a practical and long-lasting means for achieving this goal. High-hazard stands can be manipulated to reduce risk, high-risk individual trees can be removed, and low-risk stands can be tended to maintain vigor and rapid growth. Managers are encouraged to give thorough consideration of the array and potential impacts of pests as land management plans are developed, and to implement preventive treatments when these strategies are compatible with other management goals.

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